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A Giga-particle Atmospheric Trajectory Model

Carlos Cruz[1,2] , Thomas Clune[1], Leslie Lait[1,3], Shawn Freeman[1,2], Robert Burns[1,2] and Udaya Ranawake[1,4]

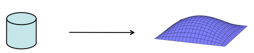
Background

We present a new parallel implementation of an atmospheric trajectory modeling framework (G-traj) which provides improved numerical accuracy, greater flexibility for specifying experiments, and sufficient raw performance to simultaneously simulate billions of parcel trajectories on suitable computing platforms.

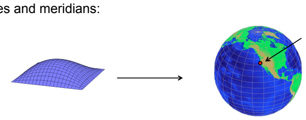
Model Implementation

The model is written in C++ for easy integration with other computing technologies. The application is parallelized using the Message Passing Interface (MPI) library and can scale efficiently on a wide variety of modern computing platforms.

How does G-traj work: Given met fields specified on a regular lat-lon grid and at regular time intervals. How do we use this to advect parcels?
Perform vertical interpolation of met fields from pressure surfaces to the pressure/potential temperature surface of interest => met data on an isobar/isentropic surface:



Interpolate isentropic surface to parcel position doing interpolation along latitude circles and meridians:



Finally interpolate met fields linearly in time to current model time.

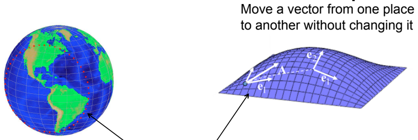
$$\vec{r}(t_1+\Delta t)=\vec{r}(t_1)+\int_{t_1}^{t_1+\Delta t}\vec{v}\,dt$$

Integration schemes : Runge-Kutta, RKF, Euler

Data interpolation methods : linear, log-linear, nearest-neighbor

Significantly improved numerical accuracy, especially near the poles. This is done by expressing integration in terms of a curvilinear parallel transport scheme:

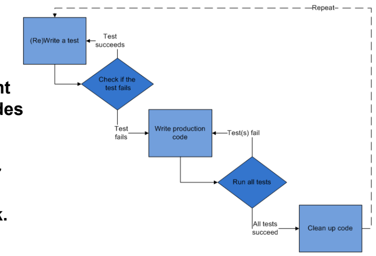
Parallel transport:
Move a vector from one place to another without changing it



Output provided : parcel histories, summary statistics, min/max quantities

Model validation and TDD

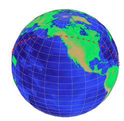
The entire package has been rigorously developed using Test-Driven Development (TDD) which both provides confidence in the implementation and should also assist other developers that wish to extend the framework.



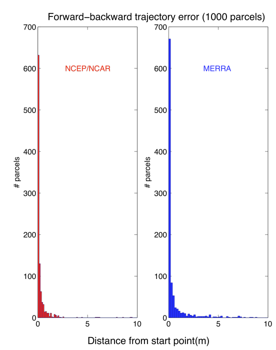
Source: wikipedia

Solid body rotation tests

Tilted solid body rotation provides a baseline synthetic wind field for assessing model performance and also allows testing of transport over the poles. A time-varying case is used to examine the errors introduced by interpolating linearly in time.



Model accuracy

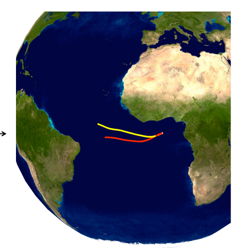


We perform full model tests with NCAR/NCEP reanalysis and MERRA wind fields to compute forward and backward trajectories of thousands of parcels. Accuracy and performance statistics from these tests show that the model efficiently generates highly reproducible trajectories.

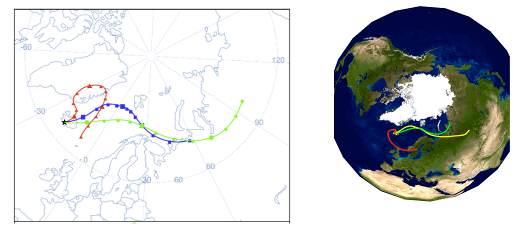
Effect of using different meteorological data sets (wind field) at different resolutions to simulate a 3-day trajectory:

NCAR/NCEP reanalysis (red) 2.5 degrees longitude, 2.5 degrees latitude,17 pressure levels, 6hr time resolution

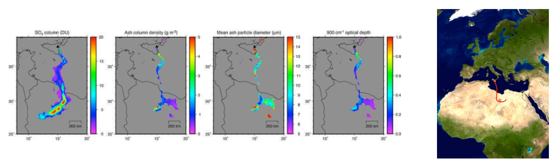
MERRA (yellow) 1.25 degrees longitude, 1.25 degrees latitude, 42 pressure levels, 3 hr time resolution



Sample runs: volcanic eruptions



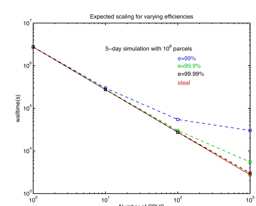
Comparison with an operational model: Kinematic trajectories from Hekla eruption (Rose et. al.) predicted by HYSPLIT (left) model and G-traj results (right). Altitudes: red=6km, blue/yellow=9km, green=12km respectively.



Comparison with observations: Mt Etna eruption (Carn et. al.) tracked by AIRS and G-traj kinematic 3-day trajectory results.

Future work

The ability to treat a large numbers of parcels is expected to enable a new generation of future experiments to explore questions related to global stratosphere-troposphere exchange, age-of-air spectra, and transport of trace gases and aerosols. Also using a massively parallel trajectory model can soon open up new solutions of problems that are not well addressed by non-parallel programs.



References
Carn, S.A. et. al. Quantifying tropospheric volcanic emissions with AIRS: The 2002 eruption of Mt. Etna (Italy), Geo. Res. Lett., Vol 32 doi:10.1029/2004GL021034, 2005
Rose, W.I. et al. Atmospheric chemistry of a 33-34 hour old volcanic cloud from HeklaVolcano (Iceland): Insights from direct sampling and the application ofchemical box modeling, J. Geo. Res., Vol. 111 (D20), doi10.1029/2005JD006872.
Schoeberl, MR; Sparling, LC. "Trajectory Modelling" in Diagnostic Tools in Atmospheric Physics. Proceedings of the International School of Physics "Enrico Fermi", 1993

[1]NASA GSFC / SIVO
[2]Northrop Grumman
[3]GEST/UMBC [4]AMTI

Contact: carlos.a.cruz@nasa.gov